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# Soil and Water Conservation Structures, Hydraulic Models and Field Applications

St. Anthony Falls Hydraulic Laboratory
University of Minnesota, Minneapolis

Advances in Agricultural Technology
Science and Education Administration
U.S. DEPARTMENT OF AGRICULTURE

AAT-NC-6
December 1980

Study conducted by the
Science and Education Administration—Agricultural Research
UNITED STATES DEPARTMENT OF AGRICULTURE
In cooperation with
Minnesota Agricultural Experiment Station
and the
St. Anthony Falls Hydraulic Laboratory
University of Minnesota

This is a revision of ARS-NC-47
"Soil and Water Conservation Structures,
Demonstrations and Field Applications"
July 1976

ISSN 0193-3701

# Contents

# Soil and Water Conservation Structures, Hydraulic Models and Field Applications

Fred W. Blaisdell, Clayton L. Anderson, and George G. Hebaus[1]

## Introduction



Soil and water conservation structures are usually designed to carry flood flows. Unfortunately, weather or impassible roads during severe storms limit opportunities to see structures passing large floods. Fortunately, models of these structures can be built in the laboratory and their performance observed under simulated severe flood conditions.

The pictures and associated information in this publication are evidence that models reliably predict the performance of field structures, that laboratory findings can be transposed to the field, and that soil conservation structures with superior hydraulic performance can be developed from laboratory tests. On the following pages pictures are shown of models and of their comparable prototypes to illustrate that the performance of laboratory and full-sized field structures is actually identical.

One point stressed is the effect of small details on hydraulic performance. All too many people—including a great many engineers—fail to realize that seemingly small changes in the design or construction of a structure can cause large changes in the performance of that structure.

For example, floor blocks in a straight drop spillway stilling basin will prevent scour in the downstream channel. However, a solid sill is usually considered easier to build and might be considered a minor change, yet replacing the floor blocks with a solid sill completely alters the performance of the outlet structure.

As another example, turning a sliced inlet (a pipe cut at an angle) upside down to make a hood inlet will make a farm pond pipe spillway or highway culvert flow full. If the pipe slope is hydraulically steep, the hood inlet will increase the flow through the pipe, decrease the depth of the headpool, and possibly prevent the dam or road from being overtopped.

Pictures of both laboratory models and field applications of soil and water conservation structures are included to show how hydraulic structures work. Details are shown of both good and poor structures—that is, designs that may be safely used as well as those that should be avoided. Differences between good and poor structures are frequently small and the effect of these differences on the performance usually cannot be predicted. This is why laboratory tests are necessary.

Also shown are pictures of water flowing through small structures installed in a portable demonstration channel. However, the demonstrations pictured do not represent laboratory testing or research. Too few people realize the tremendous amount of planning, careful testing, and thorough analysis that go into the development of a new hydraulic design. A great deal more is involved than is presented here. The purpose of the demonstrations is to give a quick look at some of the more significant results of laboratory tests of soil and water conservation structures.

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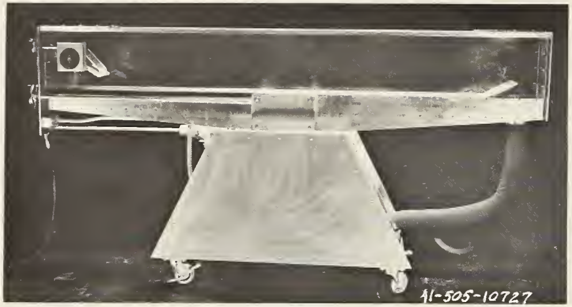



**Hydraulic demonstration channel.**



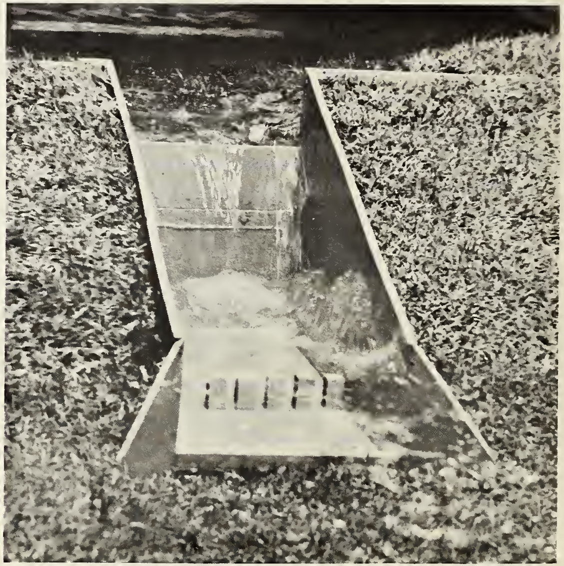
Both good and poor hydraulic performance of various types of structures can be shown with models placed in a demonstration channel such as the one pictured. In this channel a variety of flow rates can be produced simply by turning a valve. The performance of these structures during floods as well as their performance at more usual flows can also be simulated. However, the pictures of the demonstration channel structures presented here show flood flows because flood flows usually provide the most severe test of performance.

## Drop Spillways

Straight and box inlet drop spillways are used for grade and erosion control in streams, channels, gullies, highway and agricultural drainage ditches, irrigation canals, and as agricultural drain tile outlet structures. In 1978 the Soil Conservation Service built 12,514 structures under the Agricultural Conservation and Great Plains Conservation Programs.

## Straight Drop Spillway Stilling Basin

A movie "Straight drop spillway basin" shows the experimental methods used, the work required to develop improved designs, and the effects of small changes on the stilling basin performance. This 22-minute, 16 mm, color, sound movie may be borrowed by writing to the address listed in the footnote on page 1.



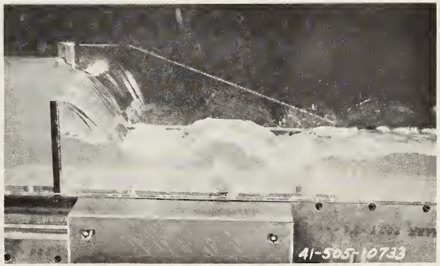
***Straight drop spillway stilling basin.*** **Double exposure without and with flow shows the basin, floor blocks, end sill, wingwalls, riprap above the spillway, and the water surface.**

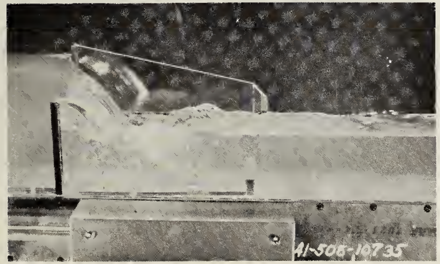
## Performance of Three Types of Stilling Basins




*Morris-Johnson stilling basin* has longitudinal sills and an end sill. Longitudinal sills are of little benefit. End sill causes standing wave that digs hole beyond end of basin.

*Wisconsin notch stilling basin* has two solid transverse sills. Standing wave caused by upstream sill lands on downstream sill. Downstream sill is ineffective and stream bed is scoured.

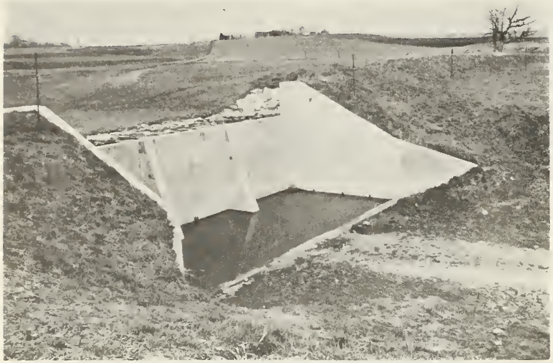



*Straight drop spillway stilling basin* has blocks instead of solid transverse upstream sill—the only important change. Flow at basin exit is smooth. No scour occurs in stream bed beyond exit.

## Morris-Johnson Stilling Basins Showing Scour

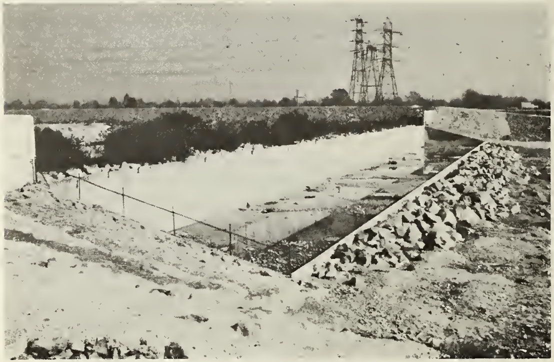
Stilling basin located in Bear Valley, Wabasha County, Minn.



1. No. downstream erosion in 1965.

2. Still looks good in May 1969.

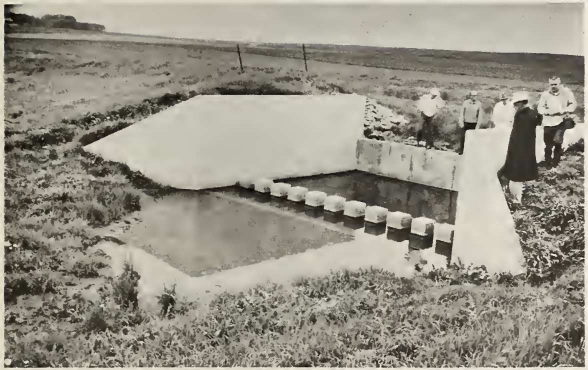
3. Flood of May 1970 caused severe scour.



Large stilling basin located in San Gabriel River, Los Angeles, Calif. Rock fills hole that scoured 15 feet or more deep.

## No Scour at Straight Drop Spillway Stilling Basin Exit

Structure built in Bear Valley, Wabasha County, Minn.



1. Looks good in 1969.

3. Riprap washed out and deposited in basin in May 1970 flood. Flow from culvert (out of picture) directed current to far side.

2. Riprap above spillway in 1969.

4. No downstream scour after May 1970 flood.

1. Under construction. Completed 1976.

—Soil Conservation Service photo

2. 1978, after near-capacity flows in 1977.

### Yocona River near Oxford, Miss.



Designed for inlet channel bank-full capacity for a 5-year frequency storm of 11,200 cubic feet per second, this 100-foot wide by 116-foot long million-dollar spillway experienced two large storms in its first year of operation. Sediment deposition pattern is typical.

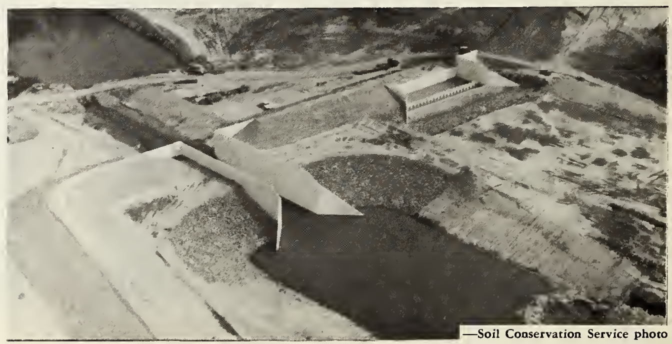
## Examples of Straight Drop Spillway Stilling Basins

### Bynum Creek near Oxford, Miss.

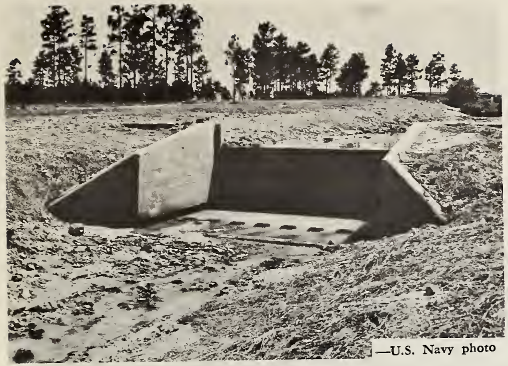
Steel sheet piling walls and concrete floor and floor blocks were used for this 150 thousand-dollar 30-foot wide by 63-foot long spillway.

### Middle Fork, Tillatoba Creek, Tallahatchie County, Miss.

For this 1.5 million-dollar spillway, a two-stage structure was economical. Low stage 34-foot wide by 120-foot long structure on left is designed to fill downstream channel bank-full—a 1-year frequency storm—before high stage 114-foot wide by 38-foot long structure on right begins to carry water. High stage flow returns to channel over riprapped channel side slope being placed at picture bottom right corner.

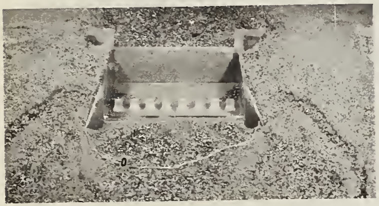


—Soil Conservation Service photo



—U.S. Navy photo

Prototype after flood.



Laboratory model after test.

Stilling basin at Whiting Field Naval Auxiliary Air Station, Milton, Fla.

Stilling basin located on San Gabriel River, Los Angeles, Calif.

No downstream scour.

—Soil Conservation Service photo

1. Full capacity flow with high tailwater.



2. No scour after flow.

Stilling basin built in Magma Channel, Florence, Ariz.

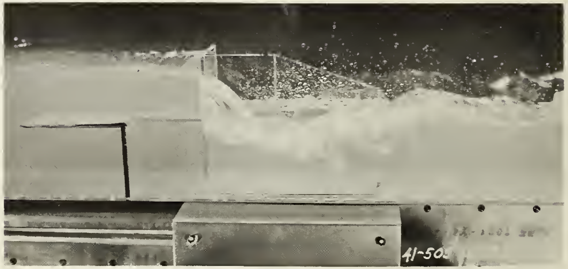
3. Local widening at basin exit should be permitted.

# Box Inlet Drop Spillway



*Box inlet drop spillway and stilling basin* is used in erosion control, as a culvert entrance, and in drainage as a ditch head and tile outlet structure. Sketch shows long crest that gives a large discharge with a low head over crest. Straight section can be lengthened and bridged to provide road crossing. Flaring outlet discharges water without erosion. Note longitudinal flow-straightening sills, end sill, and triangular flaring wingwalls.

Masonry spillway structure located in a farming area at Wykoff, Minn.



Half-model of box inlet drop spillway and stilling basin.

# Box Inlet Chute Spillway Entrance

Box inlet chute entrance used at Hunnewell Fisheries Management Area, Shelby County, Mo.

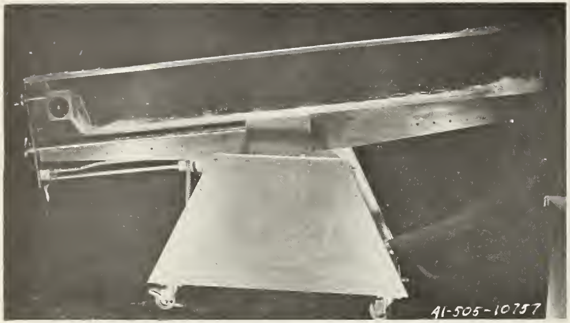
Another box inlet, chute, and stilling basin located on the Habinck Subwatershed in Woodbury County, Iowa.

1. Built in 1953, picture taken in 1958.

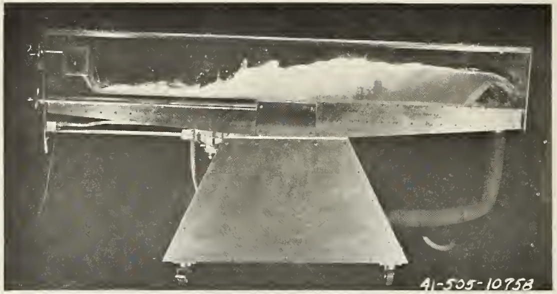
Box inlet located in Habinck Subwatershed, Monona County, Iowa.

2. Little changed in 1974.

3. Box inlet is an entrance to a culvert and chute.




*Uphill flow.* Normally water seeks its own level, but high velocity water will flow uphill.




*Hydraulic jump.* In the hydraulic jump water changes from a small depth and high velocity to a large depth and low velocity. Much destructive energy is used up in the hydraulic jump turbulence. This is good because the destructive energy used up is not available to scour the stream bed.



## High-Velocity Flow in Open Channels

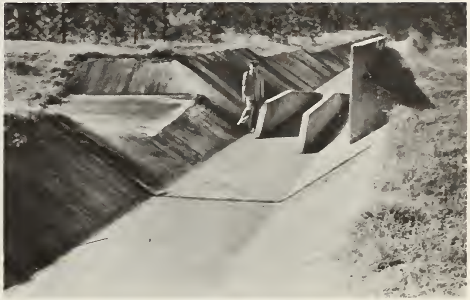
High-velocity water flow is difficult to deal with. Channel junctions or bends and obstructions like bridge piers may cause high waves that overtop the channel walls. Special care is required to design structures used where the velocity is high.

Chute at St. Anthony Falls, Minneapolis, Minn. Waves cross chute to overtop sidewalls.

Curve in spillway chute caused wave to overtop sidewall with only 1-foot depth on dam crest. Design depth is 5.27 feet.

## Whiting Field Naval Auxiliary Air Station, Milton, Fla.

Special forms of open channel junctions required to prevent sidewall overtopping were developed in the laboratory and are shown on the following three pages.



Field structure.



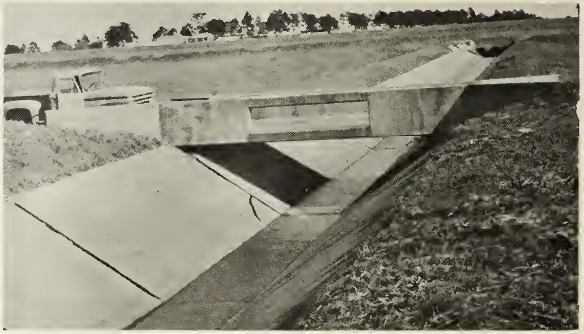
Waves in model of final design.

Waves in model of original design.

Whiting Field Naval Auxiliary Air Station, Milton, Fla.—Continued



Terrace outlet structure for moderate terrace flows.



Terrace outlet structure for relatively small terrace flows. Opening drops terrace water evenly across high-velocity water in channel.

Whiting Field Naval Auxiliary Air Station, Milton, Fla.—Continued

Channel junction for large flows.

Laboratory model.



Field structure.

## Soil Conservation Service Channels, Escondido, Calif.



Ditch junction.

Access ramp can cause waves.

Trapezoidal-to-rectangular ditch transition.

Side roughness is used to control velocity.

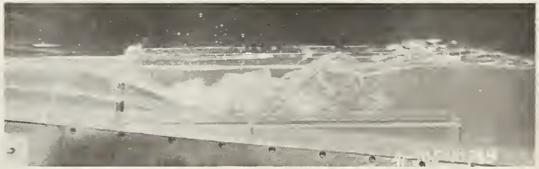
U.S. Army Corps of Engineers

Floor is tilted in this curve of the Dalton Wash channel, Los Angeles County, Calif.

Steep, concrete-lined, high-velocity channels are used by the Soil Conservation Service and Corps of Engineers to convey flood water from the mountains to the ocean through developed areas along the California coast. Similar channels are used throughout the United States where land values are high, where little space is available to build the channel as in cities, and to prevent loss of life and property from flooding.

# Culvert and Chute Stilling Basins

These stilling basins are used to dissipate energy and prevent erosion at the exit end of culverts, chutes, dams, and other spillways.



*Hydraulic jump stilling basin* has no blocks or sills. Tailwater alone is used to dissipate energy.

*SAF (St. Anthony Falls) stilling basin* length is much less than for hydraulic jump basin. Chute blocks, floor blocks, and end sill dissipate energy and prevent scour of downstream channel.

## Scour of Large Rock—A Problem



*Heavy riprap* will not prevent scour if improperly placed. At St. Anthony Falls, Minneapolis, Minn., boulders were scoured at a chute exit. Size of boulders shown by men (on wall at *left* and on boulders at *right*).

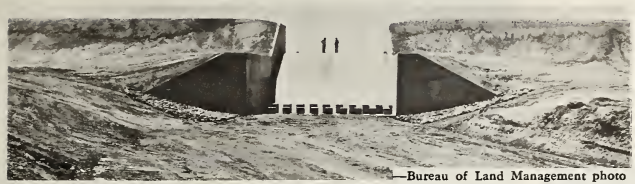
*Incorrectly placed riprap* was scoured at a pipe spillway exit on the Potomac River Watershed, W. Va.

## SAF Stilling Basin—A Solution

At the exit of a SAF chute stilling basin on Mule Creek, Iowa, the energy dissipation pool is of the expected shape after several large floods.

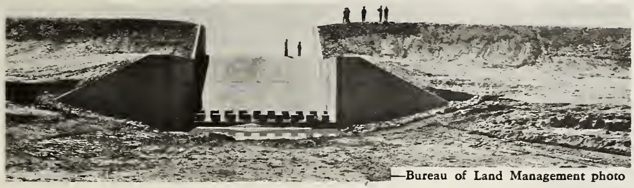
# SAF Stilling Basin

SAF chute stilling basin located in San Simon Wash, Ariz.



—Bureau of Land Management photo

1. Before flood.



—Bureau of Land Management photo

2. After 2,200 cubic feet per second flood.

—Bureau of Land Management photo

3. Mud splash on basin walls shows shape of water surface.

SAF pipe outlet stilling basins.

—U.S. Navy photo

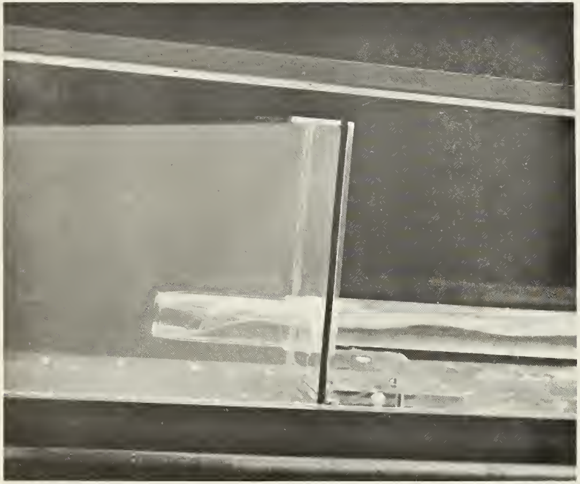
In structure at Whiting Field, Fla., end sill is under water.

In structure at Minneapolis, Minn., blocks and end sill are under water.

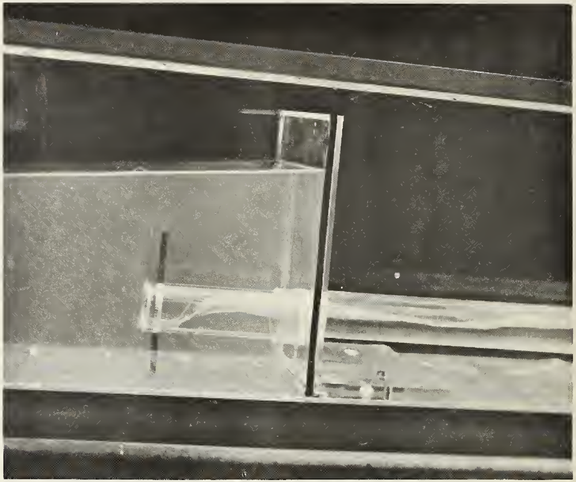
# Pipe Spillway Entrances

Pipe spillways are used for farm ponds, highway culverts, and flood control reservoirs. Spillway entrance geometry significantly affects the flow in the pipe. Pipe should flow full for maximum efficiency.

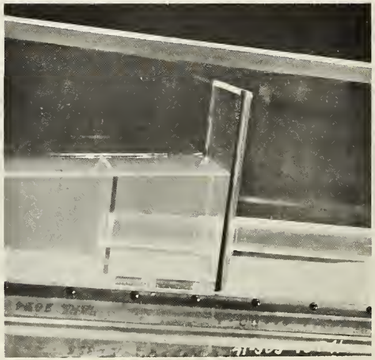




1. *Sharp-edged re-entrant entrance on a steeply sloping pipe, free outlet.* **Pipe will not flow full even though the inlet is deeply submerged. (Raising the tailwater to submerge outlet will fill pipe and lower depth over entrance.)**

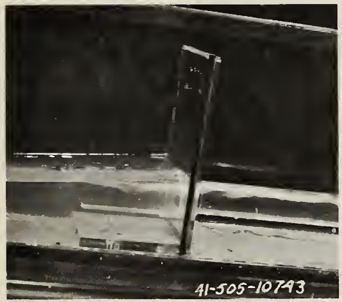


2. *Square-edged entrance in a headwall on a steeply sloping pipe.* **Pipe may fill if the entrance is submerged deeply enough.**



3. *Well-rounded entrance in a headwall on a steeply sloping pipe.* **At same discharge used for square-edged entrance, pipe flows full at a much lower depth over entrance.**

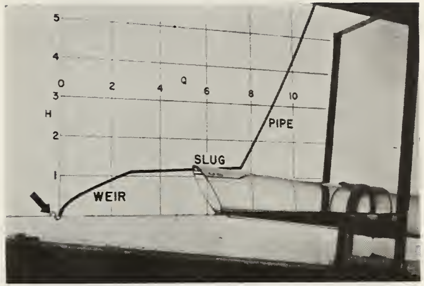

4. *Sliced entrance on a step slope.* Sharp edge at crown makes the sliced inlet work like the sharp-edged inlet. Pipe will not fill even with a high head over the entrance.



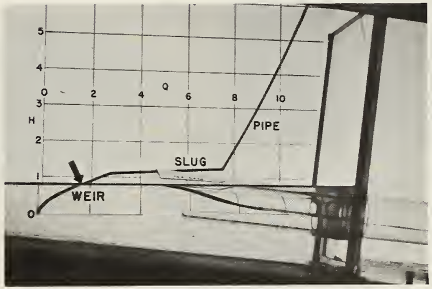

5. *Hood inlet on a steep slope.* Hood is formed by overhang of pipe cut on an angle. Pipe fills with low inlet submergence.

# Hood Inlet

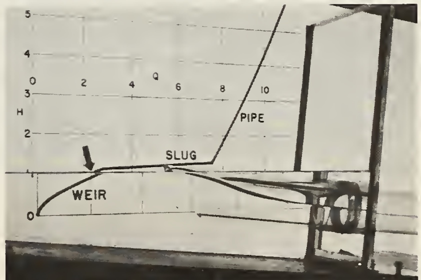
## Hood Inlet Weir Flows




1. No flow.




2. Weir flow.

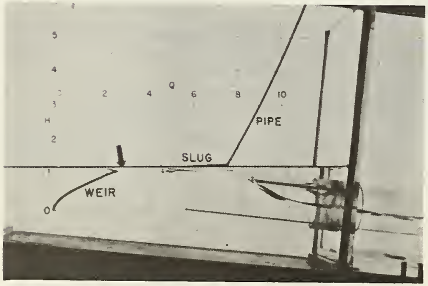



3. Water surface inside entrance is higher than pool level.

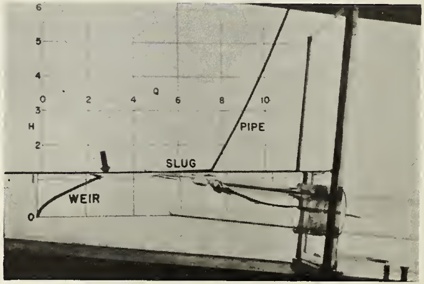
# Hood Inlet Sealing Flows

4. "Ears" form which nearly seal the entrance.


5. When the ears meet, they seal off the entrance—




6. and cause the pipe to fill for a short distance, forming a slug at the pipe entrance.

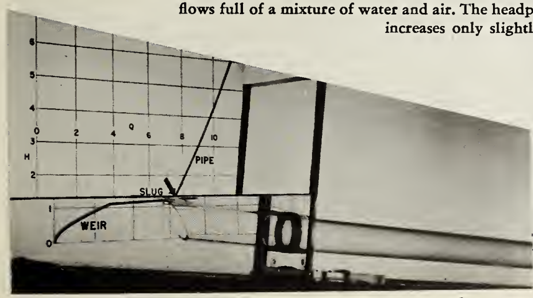



7. The slug in the pipe combines with the steep pipe to increase the flow and draw down the headpool until air is admitted.

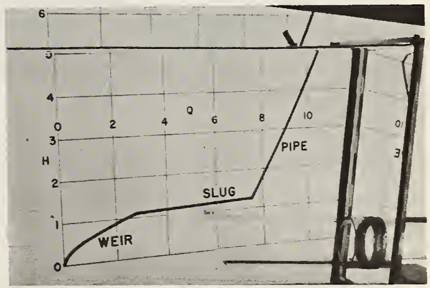

8. The slug travels down the pipe.


11. but the headpool level is so low that the antivortex plate is not submerged.


9. The slugs become more frequent as the flow increases until the pipe flows full of a mixture of water and air. The headpool level increases only slightly.




10. The pipe flows full of water with a slight increase in the flow—




12. At higher flows the pipe is full.

# Hood Inlet Spillway Entrances

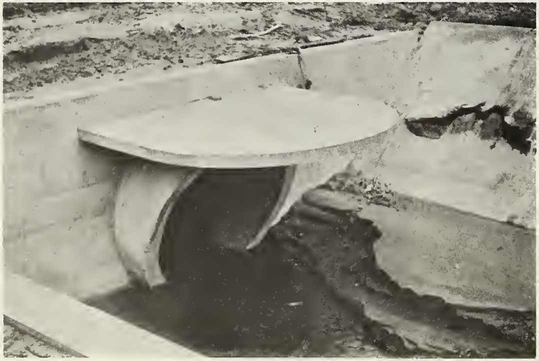


Structure located at Pine Island, Minn.

—Soil Conservation Service photo

Hood inlet built on Obion Creek, Ky.

State Highway 5 at Minneapolis-St. Paul, Minn., airport



Original construction.

New construction.

1. Hood inlets and antivortex cover.

A pair of concrete hood inlets built in Monona County, Iowa.

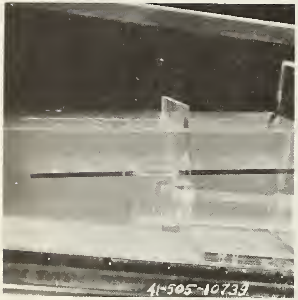
2. Closeup of hood inlets.

Hood drop inlet located in Wabasha County, Minn.

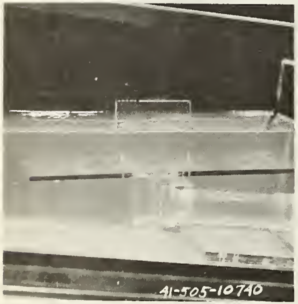
Hood inlets are used as pipe spillway entrances for many of the farm ponds built in soil conservation districts. Tens of thousands of farm ponds are built each year—the Soil Conservation Service reported 47,108 ponds and the Agricultural Conservation Program 16,323 water impoundment reservoirs in 1978. From 1936 through 1978, the Agricultural Conservation Program reports a total of 2,378,888 reservoirs.

# Drop Inlets and Antivortex Devices

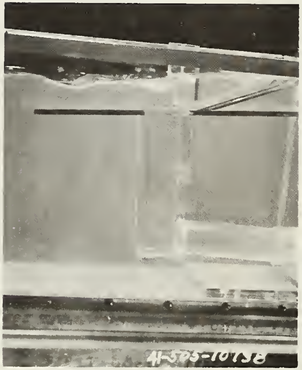
Drop inlet pipe spillway entrances and the devices used to prevent vortices can be of different shapes and sizes. Air entering through vortices, if allowed, can replace water and decrease the discharge through the spillway. Antivortex devices control vortex formation and insure that the spillway will flow full of water.



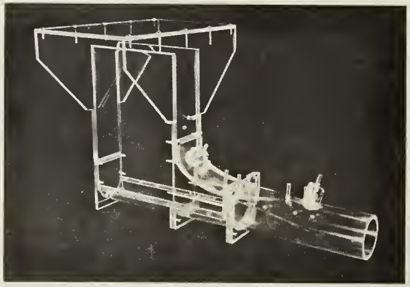

Circular drop inlet with tangential headwall.




Circular drop inlet with diametrical headwall.



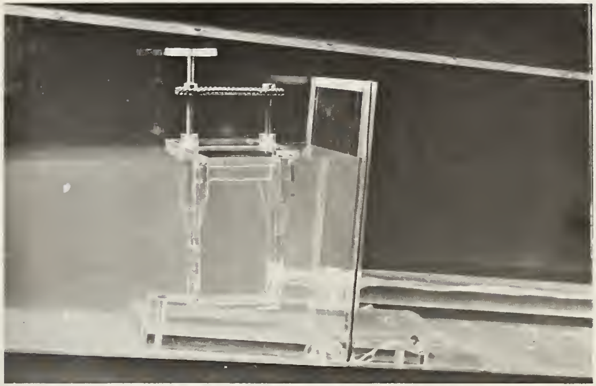
Water enters this square drop inlet over three sides. An antivortex wall occupies the fourth side. Barrel entrance can be square-edged for moderately high drop inlets.



Laboratory model of two-way rectangular drop inlet with flat plate antivortex device. Drop inlet bottom is semicylindrical. For high drop inlets, a streamlined elbow is used at the barrel entrance to prevent high-velocity flow damage. Transition at elbow exit changes flow cross section from semisquare to circular. Transition is not needed if drop inlet bottom is flat and barrel is square.

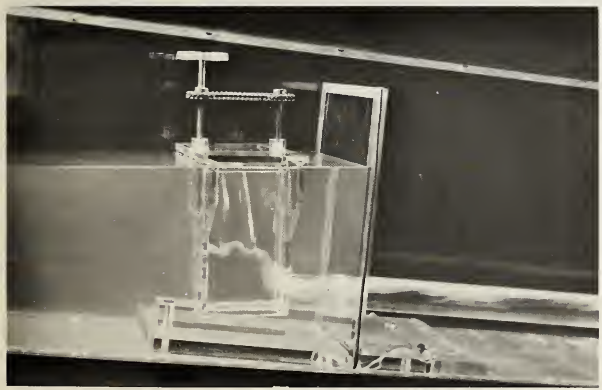
# Two-Way Drop Inlet on a Steep Slope

The two-way drop inlet gets its name because water flows over the two long sides of the drop inlet. End walls support both a vertical grating extending below the spillway crest and a sloping trash rack.
At low flows the two sides of the crest act as weirs. As the flow increases, the pool level rises until it touches the antivortex plate.
There is no further rise in the pool level until the pipe is completely full.
Within certain limits, the antivortex plate height can be set to control the pool level, a desirable feature for recreation reservoirs.

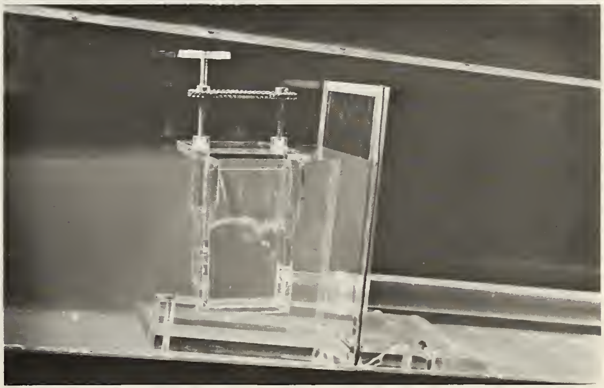


2. A low-stage inlet the full width of the drop inlet can prevent the barrel from filling.



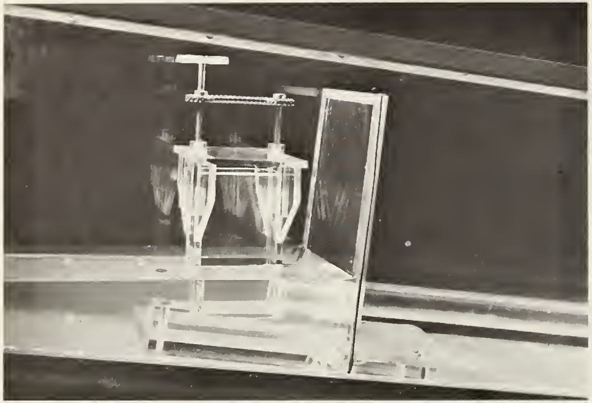


1. This inlet is three pipe diameters long by one pipe diameter wide. The height of this antivortex plate is adjustable for demonstrations. The low-stage inlet is closed.



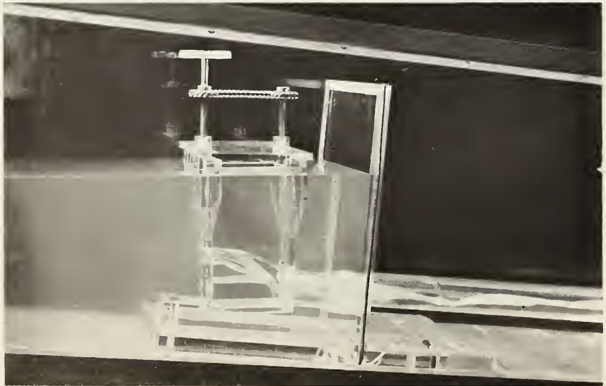
3. A low-stage inlet three-fourths the width of the drop inlet will permit the barrel to fill.

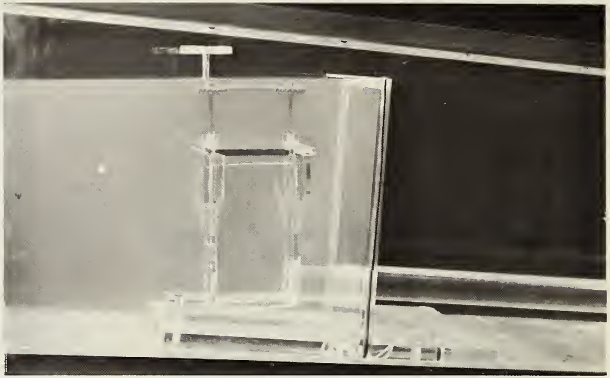
# Two-Stage, Two-Way Drop Inlet



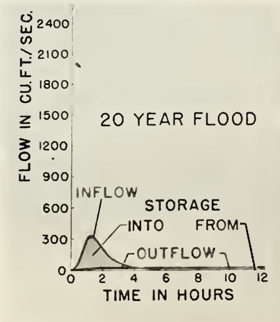
1. Normal pool elevation is the crest of the low-stage inlet. This elevation is established to provide sediment storage and storage required for beneficial use such as recreation or water supply. Low-stage inlet size is set to satisfy downstream channel capacity or stream channel stability requirements.

2a. High-stage inlet crest elevation of principal spillway is set to store a storm of given frequency without flow over the drop inlet crest. At Site No. 3, Warm Springs Run, W. Va., a 20-year storm would fill the reservoir to the principal spillway crest. All of the water would flow through the low-stage inlet. (In the demonstration channel, the flow is varied to simulate a 20-year storm. The pool level rises to the crest of the principal spillway and the reservoir then drains through the low-stage orifice.)

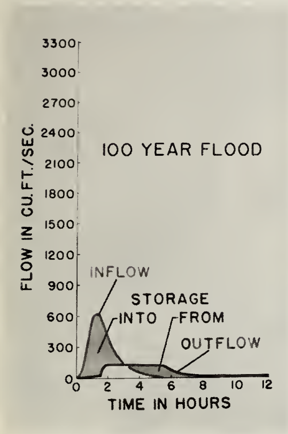




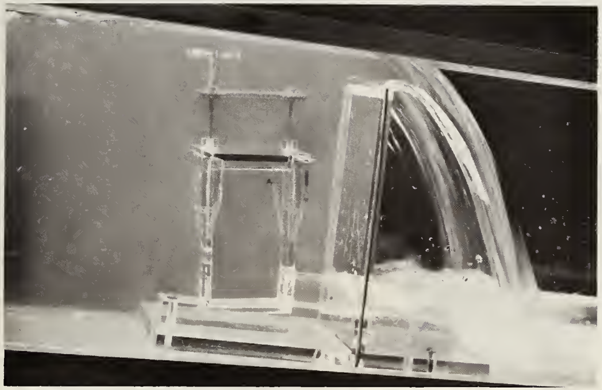
3a. The emergency spillway crest elevation—the bulkhead crest in the demonstration channel—is established by routing the principal spillway storm through the reservoir and the principal spillway. A 100-year frequency storm was used for this purpose at Site No. 3, Warm Springs Run, W. Va. For storms of frequencies between 20 and 100 years, the maximum reservoir stages are between the principal spillway crest and the emergency spillway crest. (In the demonstration channel, the flow is varied to simulate a 100-year storm. The pool level rises to the top of the bulkhead, and the reservoir drains through the principal and low-stage inlets.)



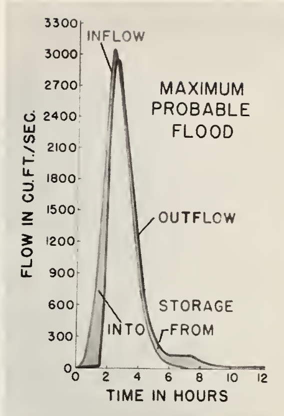

2b. Inflow and outflow hydrographs of a 20-year flood. Outflow rate is only 6 percent of the maximum inflow rate.




3b. Inflow and outflow hydrographs of a 100-year flood. Outflow rate is one-fifth of the maximum inflow rate.



4a. Storm flows exceeding the capacity of the principal spillway cause flow in the emergency (usually vegetated) spillway—over the crest of the bulkhead in the demonstration channel. The crest of the dam—the depth of the demonstration channel—is selected so that the maximum probable flood will pass through both the principal and emergency spillways without overtopping the dam. (In the demonstration channel, the maximum probable discharge is simulated by increasing the flow until it almost overtops the channel. The reservoir drains through the emergency spillway and the high- and low-stage inlets of the principal spillway.)




4b. Inflow and outflow hydrographs of the maximum probable flood. Outflow rate is 97 percent of the inflow rate.

# Two-Way Drop Inlet Spillway Entrances

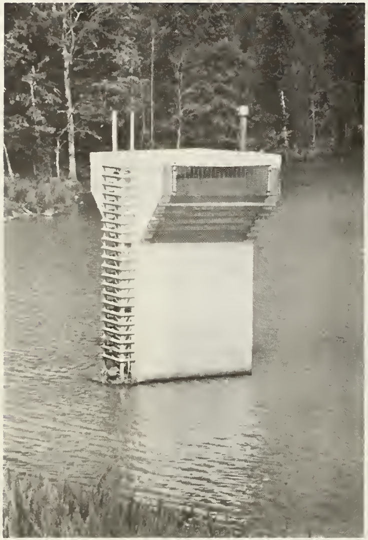


Two-way drop inlets:

—Soil Conservation Service photo

1. With two low-stage inlets in downstream wall, Upper Hocking Watershed, Ohio.

2. With chimney to discharge and aerate cool bottom water for fish, Etowah River, Ga.



3. With a single, low-stage inlet in downstream wall, South River, Ga.

4. With low-stage inlet in upstream wall, Decker's Creek, W. Va.

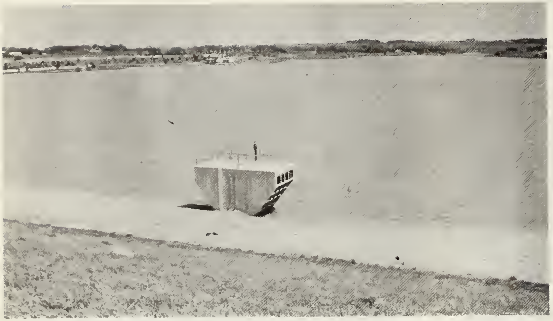
5. With round low-stage inlet in sidewall, Patterson Creek, W. Va.

The two-way drop inlet spillway entrance is used at most of the multiple-purpose (flood prevention, municipal water supply, irrigation, water-based recreation, resource conservation and development, etc.) and single-purpose dams built with Soil Conservation Service assistance. In 1978, 485 dams were built. The 1974 cumulative total was 19,500—20,770 in 1978—dams representing an investment in excess of $3 billion.

## Two-Way Drop Inlet Spillway Entrances—Continued

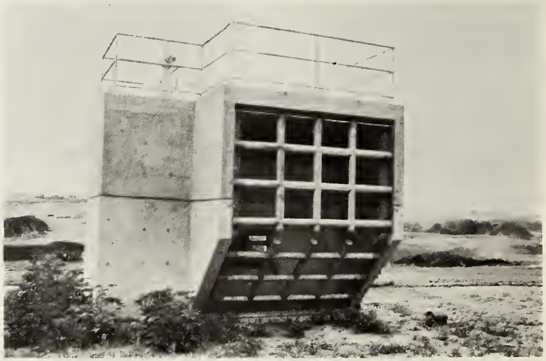
U.S. Army Corps of Engineers two-way drop inlet spillways provide flood protection and recreation for Nebraska cities.





Beach on dam, Holmes Park, Lincoln, Nebr., at left, golf course on right.

Closeup of Holmes Park drop inlet and low-stage orifice.



Drop inlet on Papillion Creek, Omaha, Nebr.

Elkhorn Lake, Upper North River, Potomac River Watershed, Va., in George Washington National Forest provides flood protection and supplies municipal water to Staunton, Va.

1. Two-way drop inlet.

2. Lake and inlet.



Stepped baffle trash rack prevents trash from entering two-way drop inlet on Mauch Chunk Creek at Jim Thorpe, Pa.

# Beaver Dam, Iowa

Beavers also know the value of flood protection and how to use spillways to prevent dam overtopping as shown by dam in Iowa.



—Iowa Conservation Commission photo

Before flood reservoir is lowered to provide space for floodwater storage.

—Iowa Conservation Commission photo

After flood reservoir is full.

—Iowa Conservation Commission photo

Pipe spillway carries floodwater
through the dam and prevents overtopping.

—Iowa Conservation Commission photo

Cantilever pipe outlet discharges
water into an energy dissipating pool.

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